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STUDENT WORKBOOK

MAGNETISM

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US ARMY ENGINEER SCHOOL - FORT BELVOIR, VIRGINIA

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MAGNETISM

INTRODUCTION

The two fundamental forces which are responsible for the wonders of electricity are electric force and magnetic force. These are the forces that make possible the operation of electric motors, generators, meters, relays, and countless other electrical devices. You have just studied the electric force as explained by the electron theory. This lesson presents many of the effects associated with magnetic force.

It is magnetic force which attracts small bits of iron and steel to the end of the common horseshoe magnet. It is magnetic force which swings a compass needle toward the north.

Magnets may be conveniently divided into two groups - natural magnets and artificial magnets. A natural magnet is an iron ore called magnetite which possesses magnetic qualities. Although pieces of magnetite are natural magnets when taken from the earth, they now have only historic value. Artificial magnets are more powerful and are made in a wide variety of sizes and shapes. Artificial magnets are used extensively in electric equipment.

This unit of instruction will help you to develop an understanding of the artificial magnets used in electric equipment. After completing this lesson you will be able to:

1. Explain the nature of magnetism.
2. Explain electromagnetism and how a permanent magnet can be made by electric means.

1. NATURE OF MAGNETISM

To understand the artificial magnets used in electric equipment, it is necessary to know the nature of magnetism.

a. Magnetic Substance

Those materials which are attracted to a magnet are called magnetic substances. Two of the more common magnetic substances are iron and steel. There are other magnetic substances which are attracted by a magnet but not so strongly as iron and steel. Some of these magnetic substances are cobalt, nickel, and manganese. It is interesting to note that some of the best permanent magnets are made from alloys. For example, alnico is made of aluminum, nickel, and cobalt. The name is derived from the first two letters of the three elements of which it is composed.

b. Nonmagnetic Substance

Most other substances are not attracted by a magnet and are said to be nonmagnetic. Examples of these nonmagnetic substances are air, wood, paper, glass, copper, aluminum, lead, tin, and silver. Magnetic force acts through any nonmagnetic substance. This can be demonstrated by moving a magnet beneath a piece of paper (nonmagnetic substance) on which there are iron filings. As the magnet is moved, movement of the iron filings can be observed.

c. Theory of Magnetism

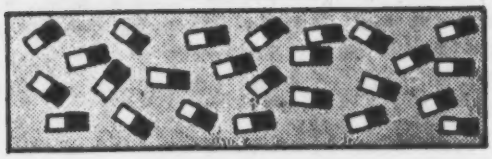
A common and one of the simple theories of magnetism is that a piece of iron or steel consists of millions of tiny magnets. This is based on the assumption that each of the molecules of a magnetic substance is itself a tiny magnet.

(1) Unmagnetized

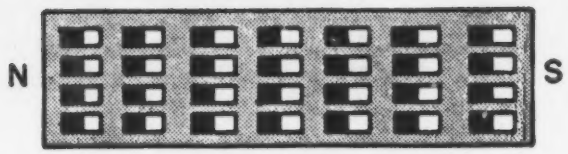
The molecular magnets that compose an unmagnetized bar of iron or steel are arranged at random (A of figure 1). With this random arrangement, the magnetism of each of the molecules is neutralized by that of adjacent molecules, and no external magnetic force is produced.

(2) Magnetized

The molecular magnets that compose a magnetized bar of iron or steel are alined so that the north poles point one direction and the south poles point the other way (B of figure 1). With this alined arrangement, the magnetism of the molecules is additive and a north pole is set up at one end of the bar and a south pole at the other end.



UNMAGNETIZED STEEL
(A)



MAGNETIZED STEEL
(B)

FIGURE 1 - THEORY OF MAGNETISM

(3) Broken Magnet

If a bar magnet is broken into several parts (figure 2), each part constitutes a magnet. The north and south poles of these small magnets are in the same respective directions as those of the original magnet. If each of these parts is again broken, the resulting parts are likewise magnets. If this breaking process could be continued, smaller and smaller pieces would retain their magnetism until each part was reduced to a molecule. It is therefore logical to assume that each of these molecules is a magnet.

d. Magnetic Poles

The magnetic poles of the magnetized bar are the areas

where the magnetic force is the greatest. If the magnetized bar were to be suspended from a string, one end would point to the north and the other end would point to the south. Long ago, when this fact was first discovered, it was decided to call the north-seeking pole of the magnet the north pole. Likewise, the south-seeking pole was called the south pole. These designations for poles of a magnet are still used.

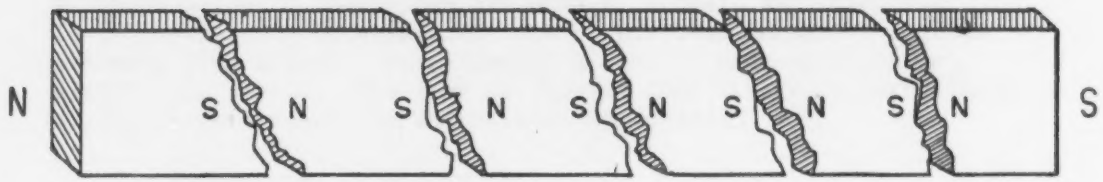


FIGURE 2 - MAGNETIC POLES OF A BROKEN MAGNET

e. Magnetic Field

The space surrounding a magnet, in which the magnetic force acts, is called a magnetic field. A visual representation of the magnetic field around a magnet can be obtained by placing a plate of glass over a magnet and sprinkling iron filings onto the glass. The filings arrange themselves in definite paths between the poles. This arrangements of the filings show the pattern of the magnetic field around the magnet (figure 3). Actually, this pattern of the magnetic field is only one of an unlimited number of possible patterns which can be produced by using one or more magnets.

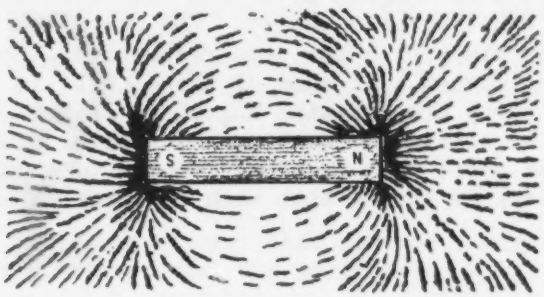


FIGURE 3 - MAGNETIC FIELD PATTERN

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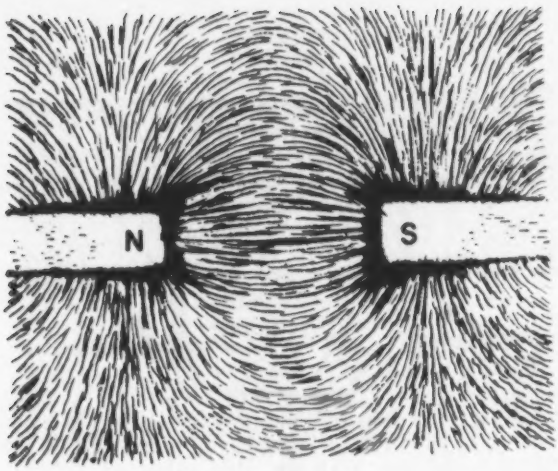


FIGURE 4 - UNLIKE POLES (ATTRACTION)

(1) Unlike Poles

If the area surrounding the north pole of one bar magnet and the south pole of a second bar magnet is sprinkled with iron filings, the pattern shown in figure 4 will be obtained. A study of this pattern shows one of the fundamental laws of magnetism - UNLIKE MAGNETIC POLES ATTRACT EACH OTHER.

(2) Like Poles

If the area surrounding the north pole of one bar magnet and the north pole of a second bar magnet is sprinkled with iron filings, the pattern shown in figure 5 will be obtained. (Two south poles will give the same effect.) A study of this pattern shows another of the fundamental laws of magnetism - LIKE MAGNETIC POLES REPEL EACH OTHER.

f. Lines of Force

Frequently it is desired to represent, by a drawing, the direction and intensity of the magnetic field about a magnet. This

is done by representing the forces in a magnetic field with a few lines called lines of force (figure 6). Note that arrowheads have been placed on each of the lines of force. The arrowheads indicate that lines of force leave the magnet at the north pole and enter the magnet at the south pole.

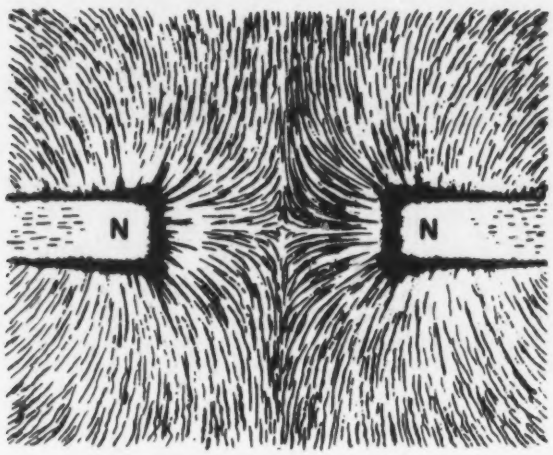


FIGURE 5 - LIKE POLES (REPULSION)

g. Magnetic Shielding

There is no known insulator for a magnetic field. If a nonmagnetic material is placed in a magnetic field, the magnetic field penetrates the nonmagnetic material. However, if a magnetic material such as soft iron, is placed in a magnetic field, the magnetic field may be redirected. This property is used to protect the sensitive mechanism of electric instruments and meters which can be influenced by stray magnetic fields and will cause errors in their readings. This is accomplished by placing a soft iron case called a magnetic shield, about the instrument (figure 7).

2. ARTIFICIAL MAGNETS

An iron, steel, or alloy bar can be magnetized by inserting the bar into a coil of insulated wire and passing a direct current through the coil, as shown in A of figure 8. The same bar may also be magnetized if it is stroked with a bar magnet, as shown in B of figure 8. The best method of making artificial magnets is by

electrical means and is described in detail.

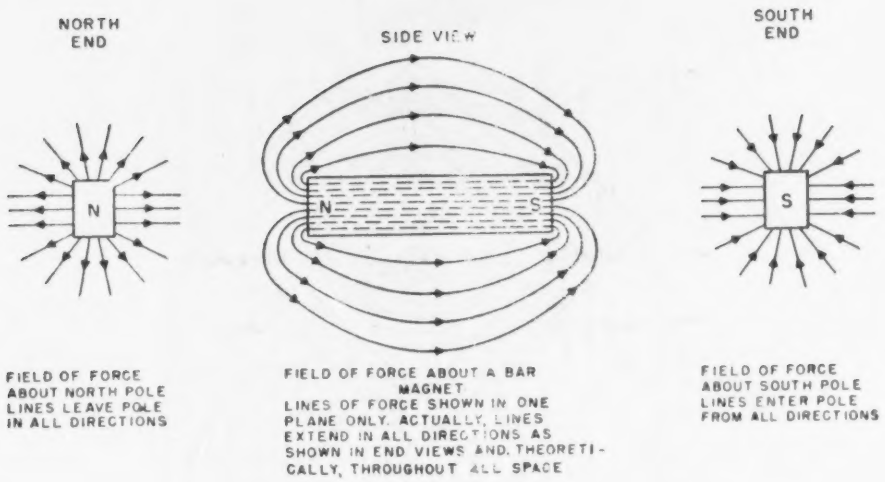

NORTH END
SIDE VIEW
SOUTH END
N
N
S
S
FIELD OF FORCE ABOUT NORTH POLE LINES LEAVE POLE IN ALL DIRECTIONS
FIELD OF FORCE ABOUT A BAR MAGNET
LINES OF FORCE SHOWN IN ONE PLANE ONLY. ACTUALLY, LINES EXTEND IN ALL DIRECTIONS AS SHOWN IN END VIEWS AND, THEORETICALLY, THROUGHOUT ALL SPACE
FIELD OF FORCE ABOUT SOUTH POLE LINES ENTER POLE FROM ALL DIRECTIONS

FIGURE 6 - LINES OF FORCE

a. Electromagnetism

Electrons moving in a conductor cause a magnetic field to build up around the conductor. This can be proven by placing a compass needle near a current carrying wire. The compass will point to the wire's magnetic field instead of to the earth's magnetic north (figure 9). When magnetism is caused by an electric current flowing through a conductor, it is called electromagnetism.

(1) Magnetic Field About A Conductor

The magnetic field produced by electron flow always lies at right angles to the current that produces it. The truth of this statement can be proven by the experiment shown in figure 10. The magnetic field is normally represented by lines of force as shown in figure 11.

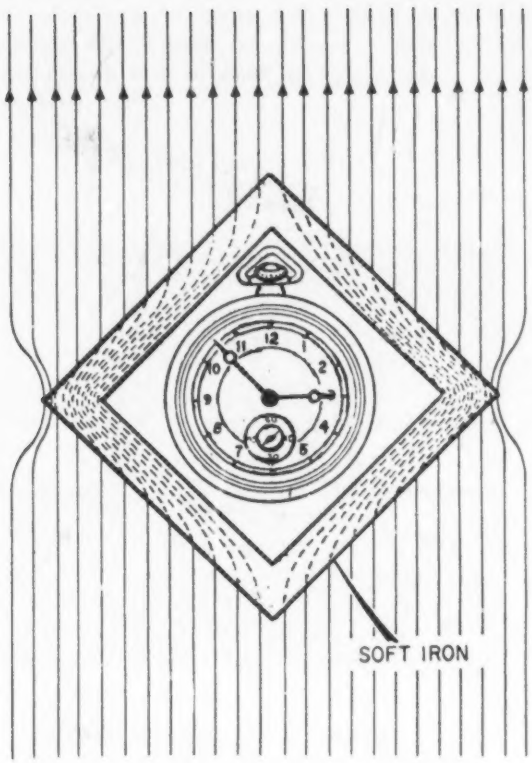


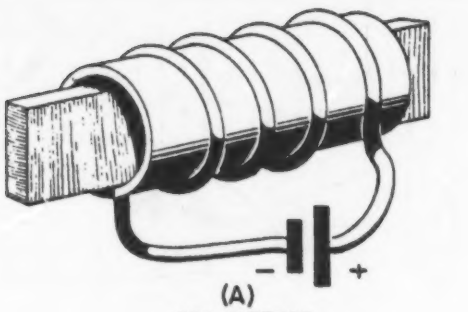
FIGURE 7 - MAGNETIC SHIELD

(2) Left-Hand Rule For A Conductor

A simple rule has been set up for finding the direction of the magnetic field when the direction of current is known. Encircle the conductor with the left hand with the thumb pointing in the direction of the current flow. The fingers will point in the direction of the magnetic field (figure 12).

(3) Magnetic Field About A Loop

If a current-carrying conductor is bent in the form of a loop, the lines of force surround the wire as when it was straight (A of figure 13). Also, when the conductor is bent into a loop, all the lines of force will enter on one side of the loop and leave on the other side of the loop (B of figure 13). Thus, a north pole is created on one side of the loop and a south pole on the other side of the loop.



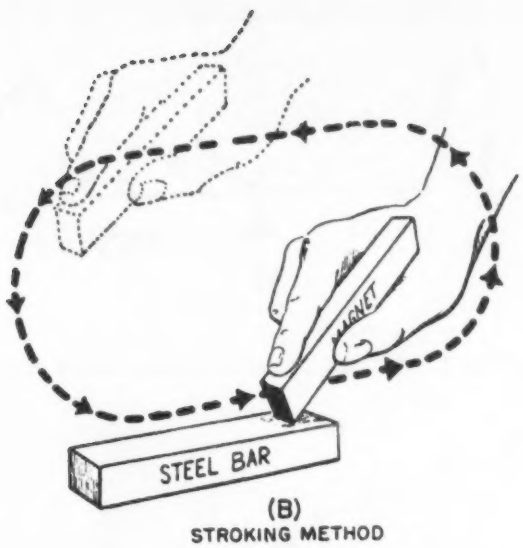


FIGURE 8 - METHODS OF PRODUCING ARTIFICIAL MAGNETS

(4) Magnetic Field About A Coil

The magnetic field resulting under the conditions shown in figure 14 is relative weak. But if several loops of wire are wound to form a coil, the strength of the magnetic field within the coil is increased. This is caused by the concentration of magnetic lines of force in a smaller area. Or, we can say that the density of the field is increased. The combined magnetic field results in a north pole on one end of the coil and a south pole on the other end (figure 14).

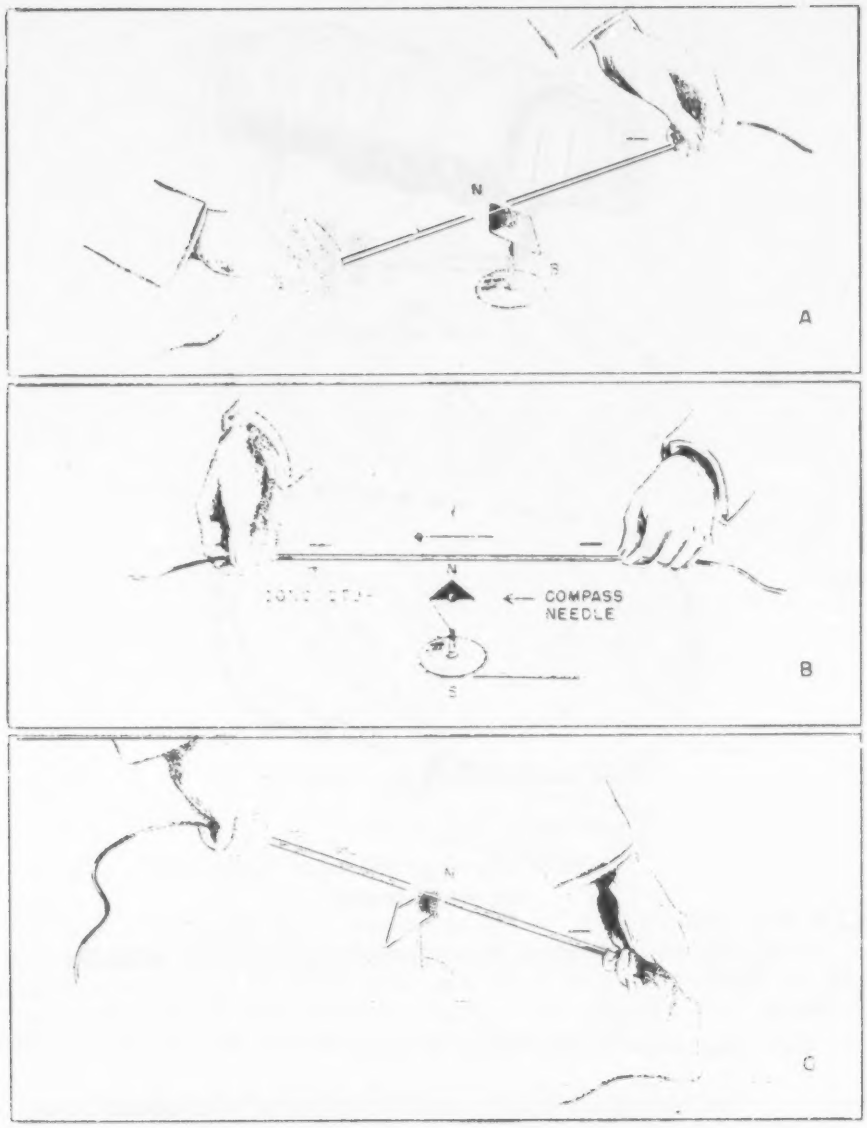


FIGURE 9 - ELECTROMAGNETISM

(5) Left Hand Rule For A Coil

When the direction of current flow through a coil is known the north and south poles can be determined by use of the

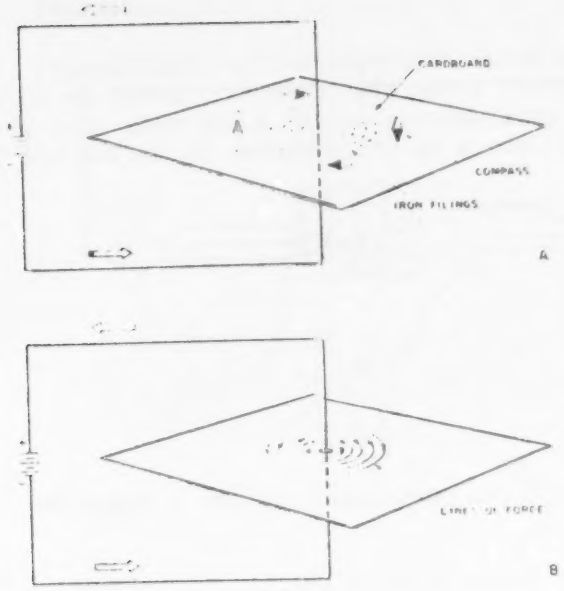


FIGURE 10 - MAGNETIC FIELD

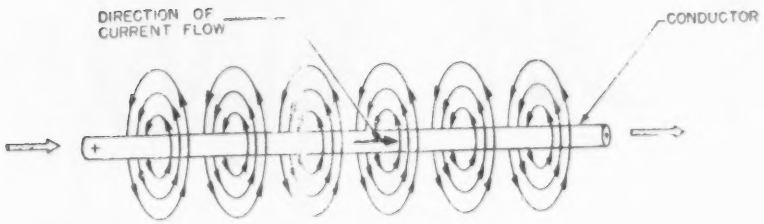


FIGURE 11 - LINES OF FORCE ABOUT A CONDUCTOR

left-hand rule for coils. Grasp the coil in the left hand, with the fingers wrapped around in the direction of current flow. The thumb will point toward the north pole (figure 15).

b. Effects of Cores

An electromagnet is normally designed to make use of a soft iron core. Iron has the ability to gather and convey lines of

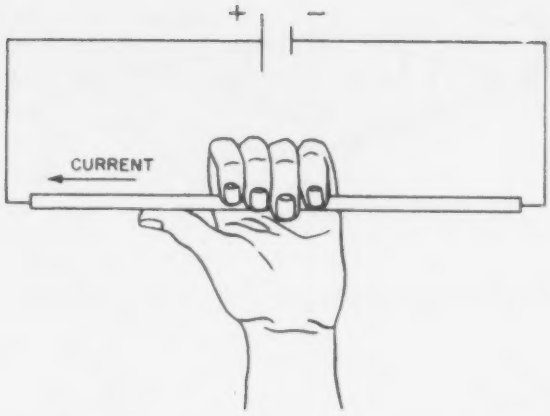
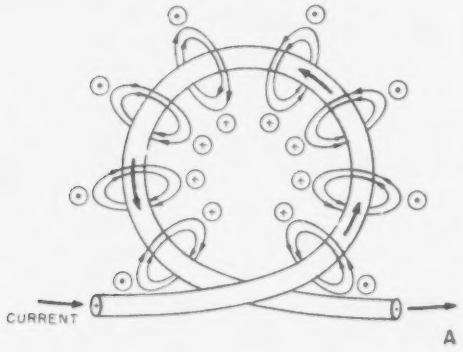


FIGURE 12 - LEFT HAND RULE FOR A CONDUCTOR



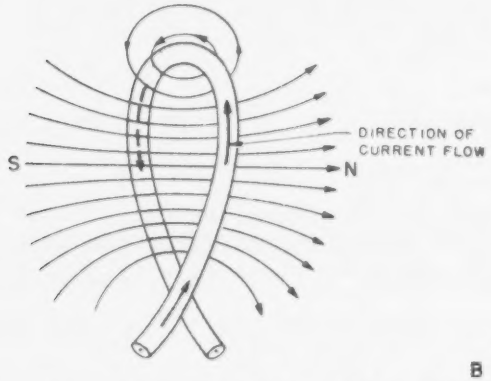


FIGURE 13 - LINES OF FORCE ABOUT A LOOP

force. This characteristic is called permeability.

(1) Permeability

Permeability is the ease with which a material conducts magnetic lines of force. A steel core has a higher permeability than air. An iron core has a higher permeability than steel. Examples of the effect of permeability on a coil are shown in figure 16.

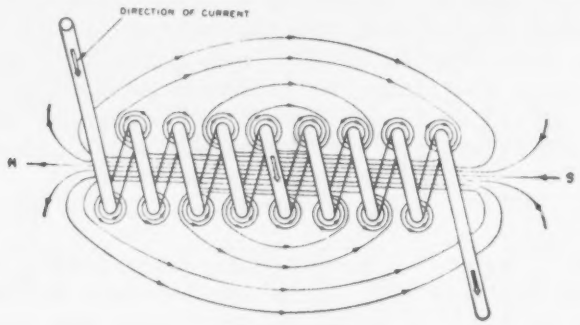


FIGURE 14 - LINES OF FORCE ABOUT A COIL

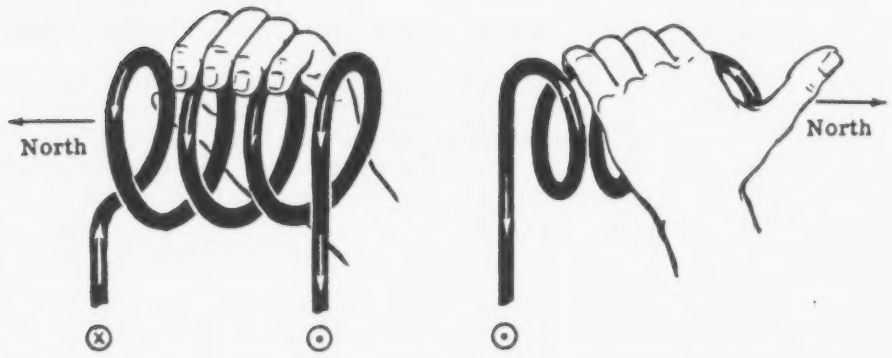


FIGURE 15 - LEFT HAND RULE FOR A COIL

(2) Retentivity

What happens to an electromagnet after the current flow has been stopped? An air core of course retains no magnetism. A soft iron core loses most of its magnetism after current flow is stopped. A hard steel core retains most of its magnetism after current flow is stopped and is said to be a permanent magnet. The

ability of a material to retain magnetism after the current flow is stopped is called retentivity. Examples of retentivity of air, steel, and iron cores, are shown in figure 17.

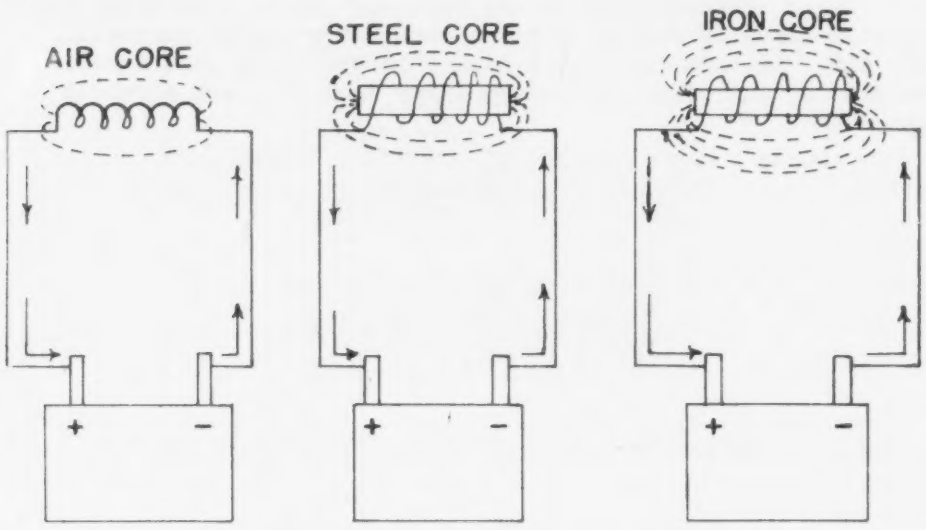


FIGURE 16 - PERMEABILITY

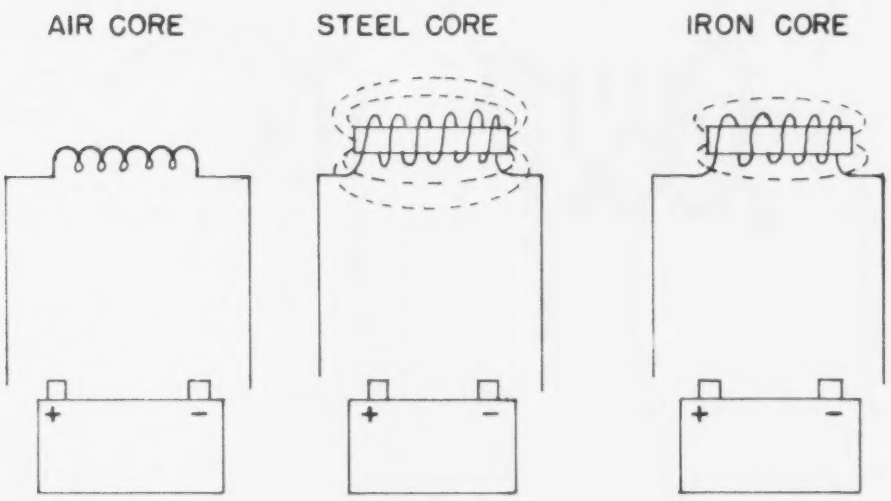


FIGURE 17 - RETENTIVITY

SUMMARY

An electric current (flow of electrons) always produces a magnetic field. In a wire, the current flow causes the magnetic lines of force to circle the wire. It is thought that these lines of force result from the movement of the electrons along the wire. As they move, the electrons "send out" the lines of force. When many electrons move, there are many lines of force (the magnetic field is strong). Few electrons in motion means a weak magnetic field or few magnetic lines of force.

The magnetic field produced by current flowing in a loop of wire must follow the curve of the wire. If two loops are made in the conductor, the magnetic lines of force will circle the two loops almost as though they were a single loop. However, the magnetic field will be twice as strong since the lines of force of the two loops combine. Increasing the number of loops still further, increases the magnetic field accordingly. Many loops of wire are normally referred to as a coil.

The magnetic strength of a coil can be greatly increased by wrapping the loops of wire around an iron core. The iron core passes the lines of force with much greater ease than air. With this great increase in the number of lines of force, the magnetic strength of the electromagnet is greatly increased, even though no more current flows through it. Practically all electromagnets use an iron core of some kind.

Electromagnets can be in many shapes and have many uses. The coils in electric gages and meters, the field coils in motors and generators, solenoids, relays, and magnetic circuit breakers are just a few of the uses of an electromagnet.

STUDY QUESTIONS

1. _____ _____ are those materials which are attracted to a magnet.

2. A substance that has its molecules arranged at random is _____.

3. A substance that has its molecules alligned is _____.

4. The _____ _____ of the magnetized bar are the areas where the magnetic force is the greatest.

5. The space surrounding a magnet, in which the magnetic force acts, is called the _____ _____.

6. Magnetic lines of force are directed from the _____ pole to the _____ pole.

7. Like poles _____ , unlike poles _____.

8. Electrons moving in a conductor cause a _____ _____ to build up around the conductor.

9. The field produced by electron flow always lies at _____ angles to the current that produces it. This is shown by the _____ _____ rule.

10. Three ways to increase the strength of an electromagnet are: _____ _____ _____, _____ _____ _____, and _____ _____ _____.

11. _____ is the ease with which a material conducts magnetic lines of force.

12. Retentivity is the ability of a substance to _____ _____ after the current flow through it is stopped.

STUDENT NOTES

INTRODUCTION

DEVELOPMENT

1. T. V. PRESENTATION

2. HISTORY OF MAGNETISM

3. POLARITY

4. MAGNETIC SUBSTANCE

5. NON-MAGNETIC SUBSTANCES

6. TYPES OF MAGNETS

7. MAGNETIC FIELDS

8. METHODS OF MAGNETIZING SUBSTANCES

9. HANDLING OF MAGNETS

10. MAGNETISM AND ELECTRICITY

11. REVIEW OF TERMS

SUMMARY

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